# Black Holes in our Galaxy

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# Dynamically Established BH Systems

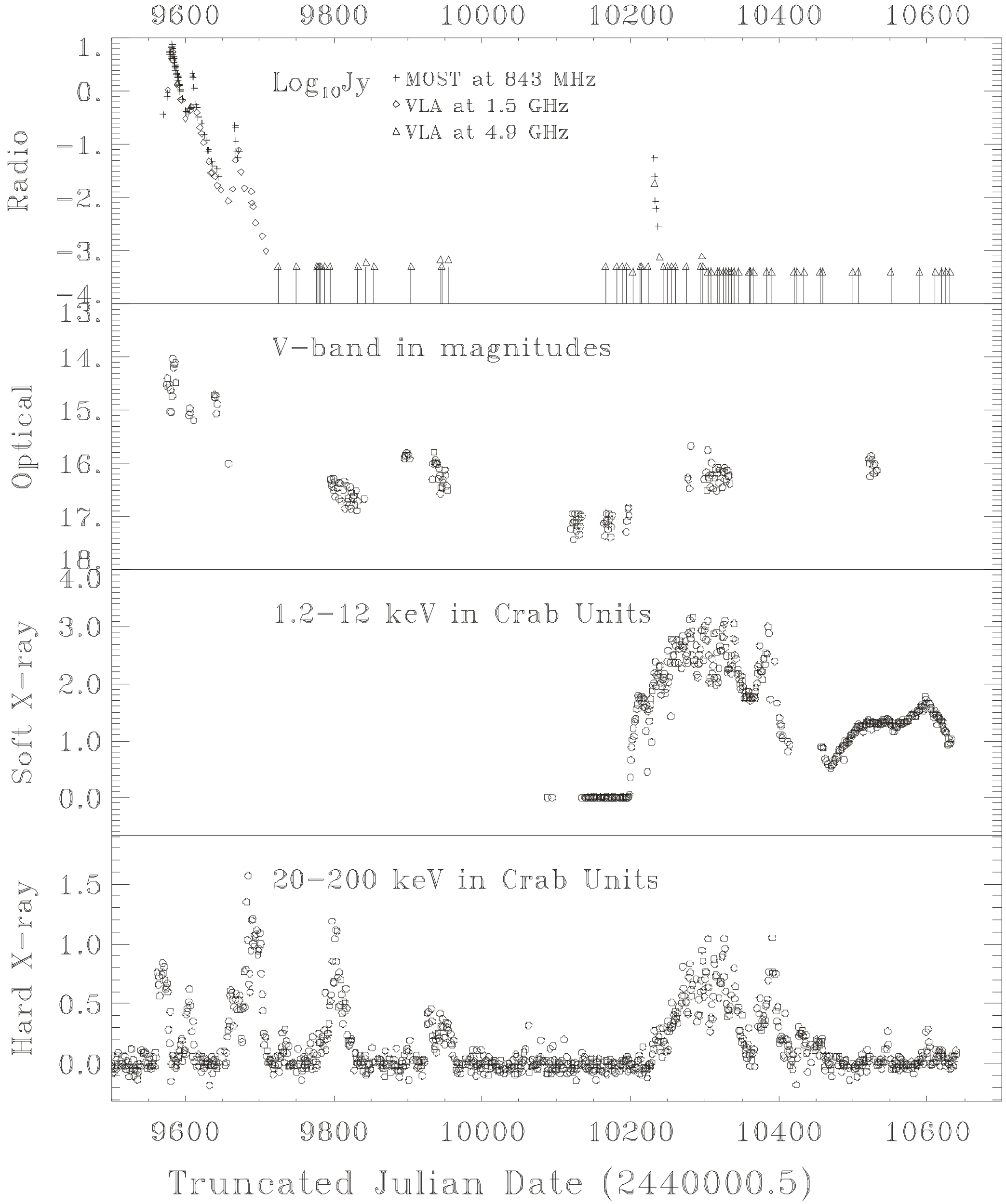
Optical and infrared measurements can be used to estimate the mass of candidate black holes. Such observations constitute the strongest evidence for the existence of stellar-mass black holes in binary systems. Currently there are at least 10 systems for which dynamical mass determinates result in the compact object having mass greater than 3 $M_0$, the theoretical upper limit of a neutron star. Hard X-ray surveys can constrain the number of black hole X-ray binaries, which may be in

| **Source Name** | **Alternate Name** | **BH Mass ($M_{sun}$)** |
|---|---|---|
| 0538–641 | LMC X-3 | 7 – 14 |
| 0540–697 | LMC X-1 | 4 – 10 |
| GRO J 0422+32 | XN Per 1992 | 3.57 ± 0.34 |
| A 0620–00 | XN Mon 1975 | 4.9 – 10 |
| GRS 1124–683 | XN Mus 1991 | 5.0 – 7.5 |
| GRO J 1655–40 | XN Sco 1994 | 7.02 ± 0.22 |
| H 1705–250 | XN Oph 1977 | 4.9 ± 1.3 |
| 1956+350 | Cyg X-1 | 7 – 20 |
| GS 2000+25 | XN Vul 1988 | 8.5 ± 1.5 |
| GS 2023+338 | V404 Cyg | 12.3 ± 0.3 |

# Multifrequency Observations

Black holes in binary systems can be detected from their broadband emission during episodes of matter accretion from their companion stars. In recent years, the ability to perform multifrequency observations of black hole binaries has led to significant advances in revealing the underlying emission processes and physical properties in these systems. The optical and infrared observations are important for determining the system parameters, such as the companion star type, orbital period and separation, inclination angle, and the black hole mass. The radio observations are useful for studying high-energy electron acceleration processes, jet formation, and particle transport. X-ray and gamma-ray observations probe the inner accretion disk region and the fundamental physics of the accretion disk under extreme conditions of temperature, pressure, and gravitational stress.

# Multifrequency Observations, continued, part 2

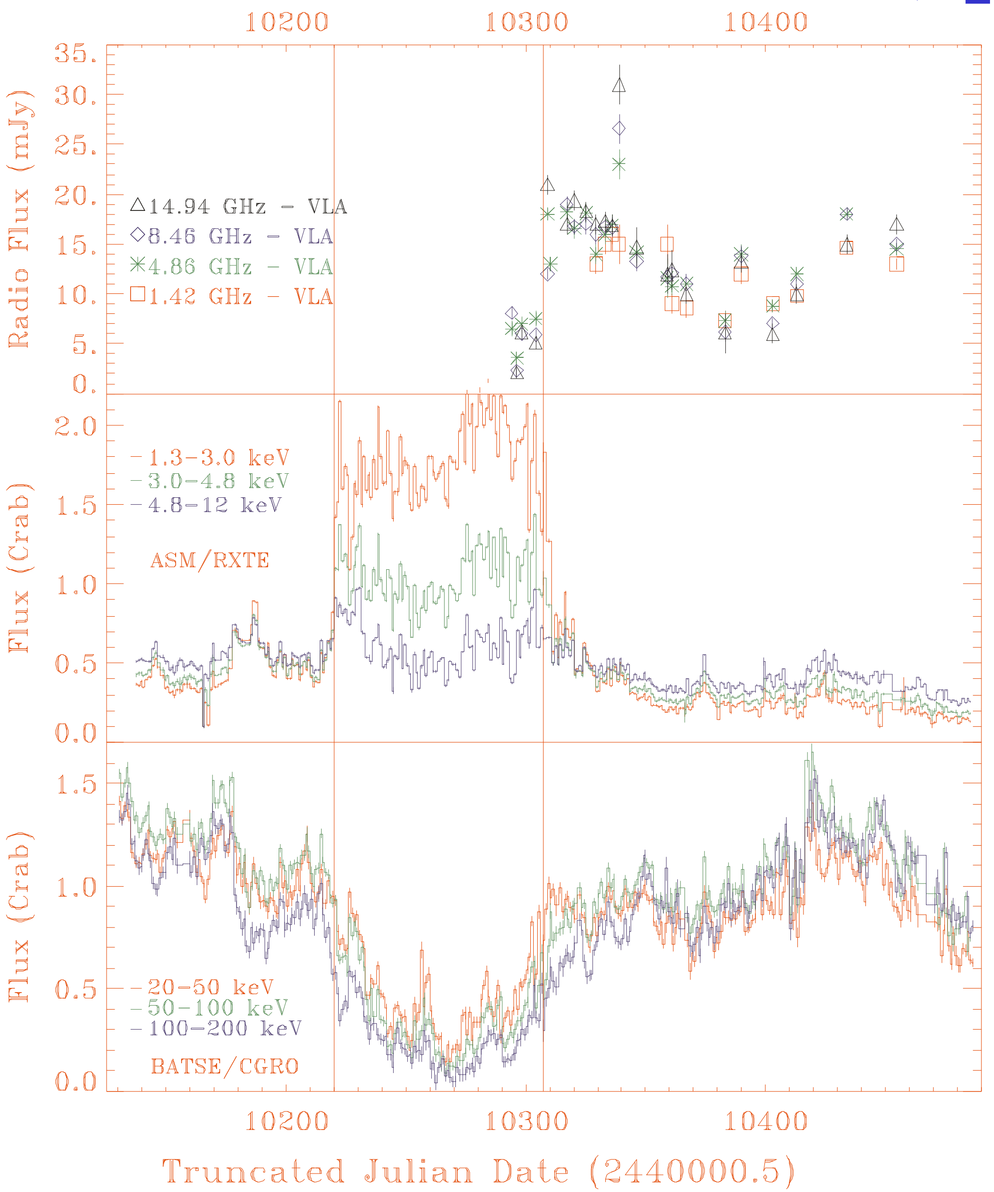



At left: Flaring episodes of the transient GRO J1655-40, which exhibits super-luminal radio jets.

Strong hard X-ray and gamma-ray flares not accompanied by radio flares indicate that the high-energy emission is not produced in the jets.

The figure is from Zhang et al. 1997, Proc. 4th Compton Symp., AIP Conf. Proc 410, p. 141.

# Multifrequency Observations, continued, part 3

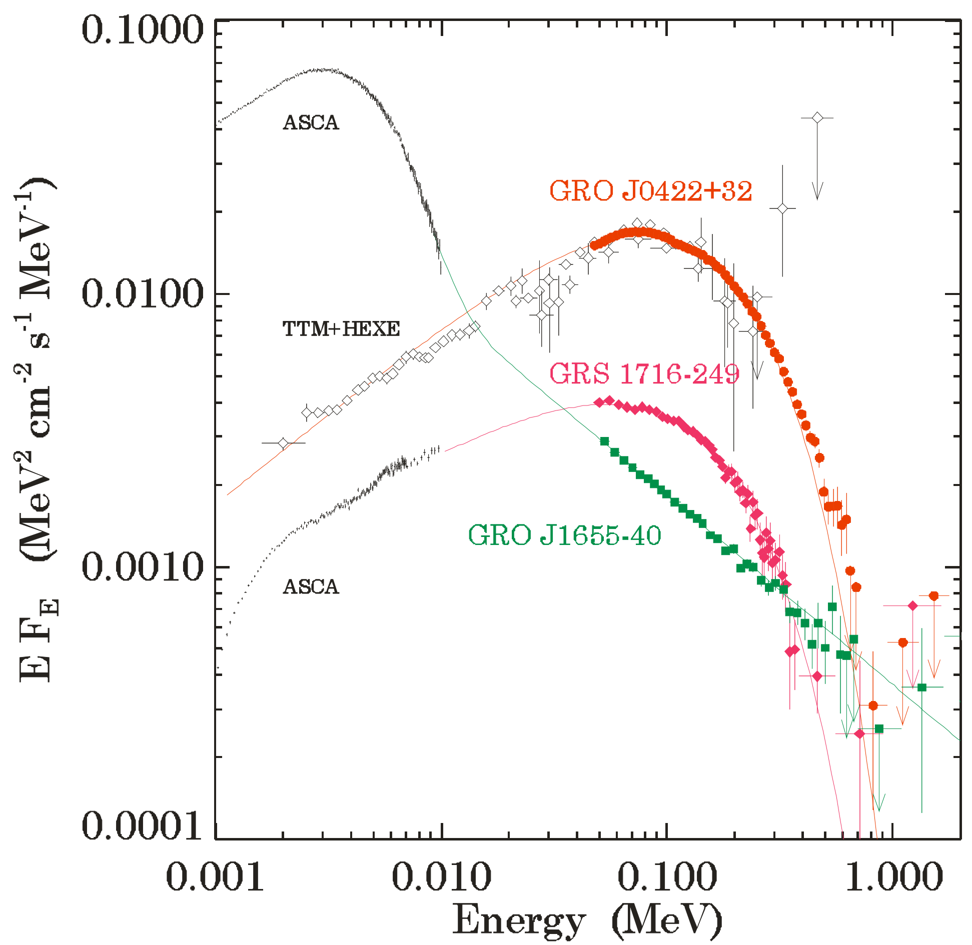



At left: Spectral state changes in the persistent source Cyg X-1. Soft X-ray emission is anti-correlated with hard X-ray and gamma-ray emission. The transition from the X-ray high state is marked by a radio flare. The figure is from Zhang et al. 1997, ApJ, 477, L95.

# High-Energy Emission

The high-energy (~1-1000 keV) emission of black hole binary systems comprises primarily two components - soft and hard - that trace the physical processes near the inner edge of the disk of matter accreted from the companion star.

Several high-energy states have been observed. Two are shown at right. In the "X-ray high/soft" state, the soft component is dominant. It is emitted from the inner accretion disk and can be well modeled by a multi-color disk black-body spectrum, where the temperature falls as radius $r^{-3/4}$. The hard component is a simple power law and, although it is not well understood, may be the



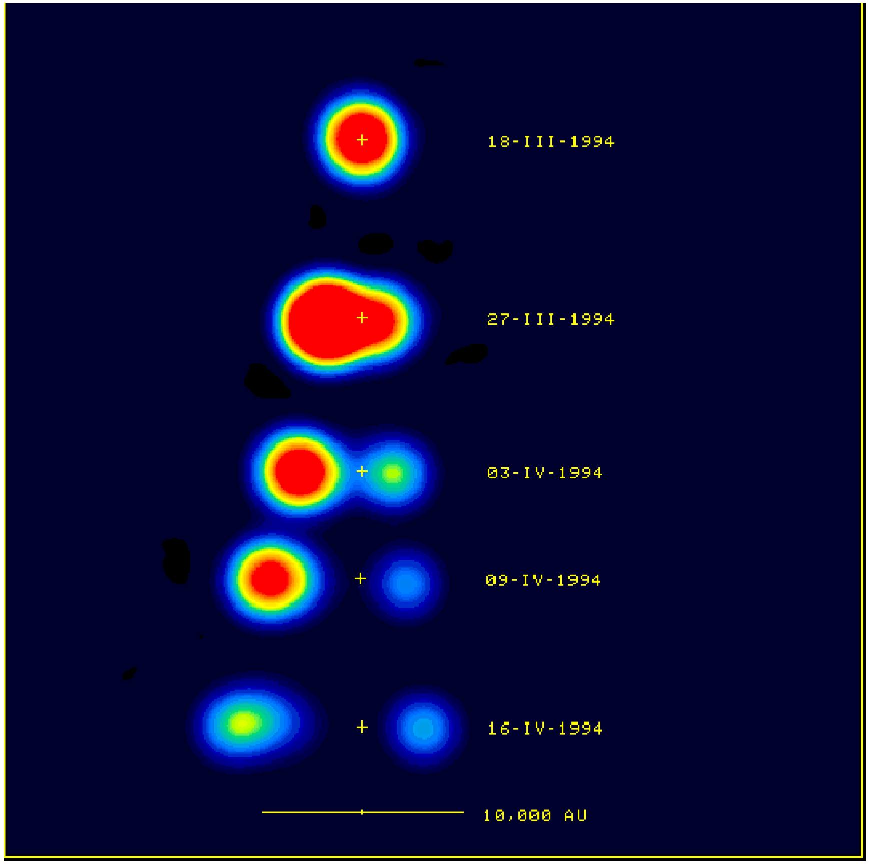
# High-Energy Emission, continued

In the “X-ray low/hard” state, the black-body component is weak or absent, having been Compton up-scattered to gamma-ray energies by a thermal plasma with temperature ~100 keV. The plasma likely exists either as a hot inner disk or as a patchy corona above a cold disk.

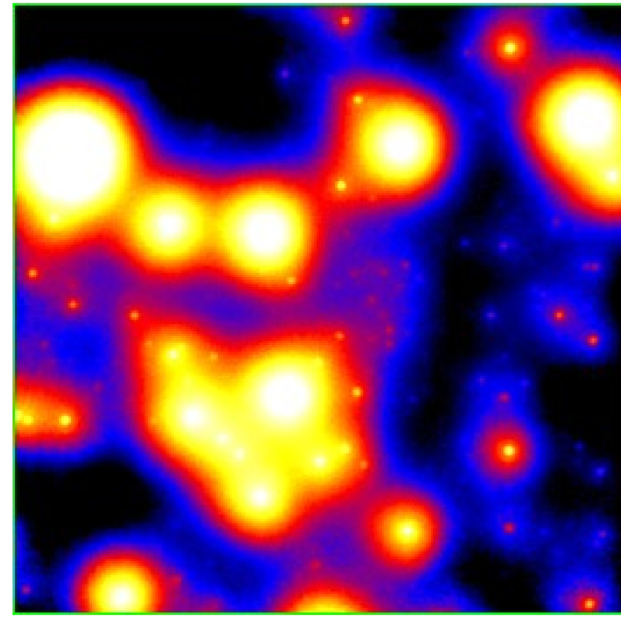
X-ray state changes are known in a number of sources. Recent models that emphasize the role of advection of mass-energy across the event horizon may help explain such state transitions.

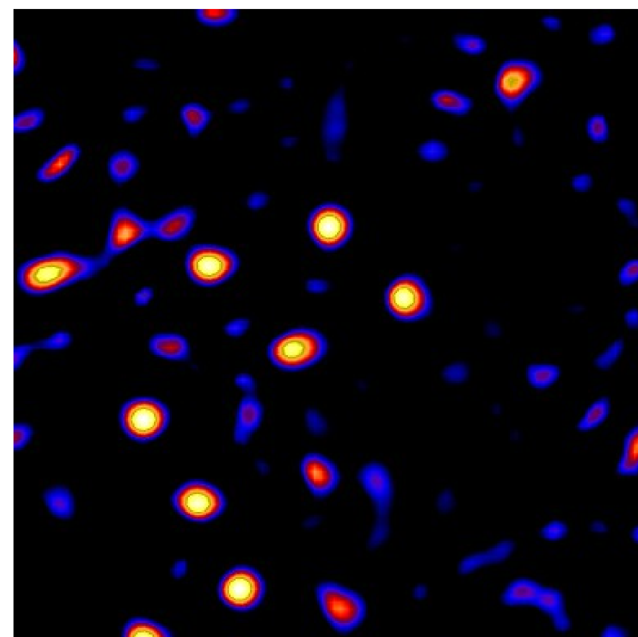
# Superluminal Motion

Relativistic, radio-loud jets from the cores of external Active Galaxies have been known for some years. Recently, such apparent superluminal motion has been detected from several objects within our Galaxy for the first time. A sequence of 3.6-cm radio images from the black hole candidate GRS 1915+105 shows radio-luminous ejecta moving in the sky. The images were taken with the Very Large Array with an angular resolution of 0.2 arc seconds. The illusion of **superluminal** motion arises when a relativistic blob of emitting matter is ejected close to our line of



# The Galactic Center





More than a quarter century ago, it was suggested that galaxies such as our own Milky Way may harbor massive, though possibly dormant, central black holes.  Definitive proof for or against the existence of a massive central black hole lies in the assessment of the distribution of matter in the central few parsecs of the Galaxy.  Assuming that gravity is the dominant force, the motion of the stars and gas in the vicinity of the putative black hole offers a robust method for accomplishing this task, with the objects located closest to the Galactic Center providing the strongest constraints on the black hole hypothesis.

Images of the core of our Galaxy  such as those here of the inner 6" ´ 6" (upper) and 1" ´ 1" (lower)  are now available with unprecedented resolution from the W. M. Keck 10-meter telescope.  Tracking the motion of some ~100 stars in these and similar images implies a central mass of 2.6±0.2 ´ $10^6$ M¤ interior to a radius of ~0.01 pc (1 pc = 3.3 light years).  The inferred central mass density is greater than for any stellar cluster and leads to the

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